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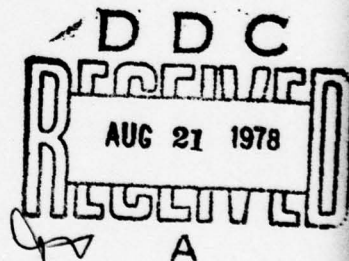
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A NOTE RELATING TWO DECISION SYSTEMS

Charles Lewis
University of Illinois

ABSTRACT

A useful and comprehensive framework for applied statistical decision theory has been provided by Raiffa and Schlaifer (1961). More recently, Luce and Krantz (1971) gain an axiomatic treatment of what they called conditional expected utility. Specifically, probability, utility, and the expression of preference in terms of conditional expected utility were all developed from a set of non-numerical axioms about preference orderings. It is the purpose of this note to investigate the connections between the systems of Luce and Krantz and Raiffa and Schlaifer, primarily through a translation of Raiffa and Schlaifer's terminology into that of Luce and Krantz.

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A NOTE RELATING TWO COLLISION SYSTEMS

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ABSTRACT

A useful and comprehensive framework for applied statistical decision theory has been provided by K. Ito and S. Kudo (1961). More recently, Lewis and Kudo (1967) gave an extensive treatment of what they called "conditional expected utility." Specifically, probability, utility, and the expression of preference in terms of conditional expected utility were all developed from a set of non-axiomatic axioms about preference ordering. It is the purpose of this note to investigate the connection between the systems of Lewis and Kudo and Kudo and Lewis, primarily through a translation of Kudo and Lewis's terminology into that of Lewis and Kudo.

Author	James L. Lewis
Title	A Note Relating Two Collision Systems
Journal	Journal of the American Statistical Association
Volume	62
Number	318
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A NOTE RELATING TWO DECISION SYSTEMS^{*}

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Raiffa and Schlaifer (1961; henceforth referred to as RS) provided a useful and comprehensive framework for applied statistical decision theory. More recently, Luce and Krantz (1971; henceforth referred to as LK) gave an axiomatic treatment of what they called conditional expected utility. Specifically, probability, utility, and the expression of preference in terms of conditional expected utility were all developed from a set of non-numerical axioms about preference orderings. There is a detailed description of the LK system in Krantz, et al. (1971, pp. 369-420), at the end of which an interest is expressed in possible connections with the RS framework. It is the purpose of this note to investigate these connections, primarily through a translation of RS terms into those of LK.

A brief outline of the elements of statistical decision-making as provided by RS (pp. 3-15) is in order. There are four sets and two functions to consider at the outset. The sets are acts, $A = \{a\}$; states, $\theta = \{\theta\}$; experiments, $E = \{e\}$; and samples or observations $Z = \{z\}$. The first function is u , with $u(e, z, a, \theta)$ a real number representing the utility of the consequence of conducting experiment e , observing z , and

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selecting act a when θ is the true state of the world. The second function (or family of functions), $P_{\theta,z|e}$, which for each $e \in E$ assigns a probability measure to $\theta \times Z$, referred to as the possibility space.

The conditional probability notation used here is not strictly appropriate, since e is not a subset of $\theta \times Z$. It will be useful to remedy this as follows: Let Z_e be the sample space associated with experiment e and let Z be the disjoint union of all the Z_e such that $e \in E$:

$$Z = \bigcup_{e \in E} Z_e .$$

Then the possibility space may be rewritten as

$$\theta \times Z = \theta \times \bigcup Z_e = \bigcup (\theta \times Z_e) .$$

If $\theta \times Z_e$ is identified with e , then conditioning on e becomes a formal possibility. This leaves open the question of a probability measure on E itself, but it is not an important question since only the conditional measures will be of interest. More generally, most details concerning the probability measure on $\theta \times Z$ are left unspecified.

The RS system is applied to decision problems at three primary levels. Given the choice of e and the observation of $z \in Z_e$, preferences among acts are specified in terms of conditional expected utilities

$$E[u(e, z, a, \theta) | z] \tag{1}$$

where, to be more precise, the conditioning is taking place on the set $\theta \times \{z\} \subseteq e$.

The next level of decision-making requires the introduction of decision functions

$$d: Z_e \rightarrow A ,$$

which describe the choice of an act given the outcome of experiment \underline{e} .

With \underline{e} fixed, \underline{d} should be chosen to maximize

$$E[u(e, z, d(z), \theta) | e] \quad (2)$$

Such a function may be constructed by choosing, for each $z \in Z_a$, an act \underline{a} which maximizes (1). As demonstrated in RS (p. 15), this process defines a \underline{d} which maximizes (2). This is described as establishing the equivalence of extensive and normal forms of analysis.

Finally, the decision maker may consider the choice of \underline{e} . Here one should select the experiment whose maximal value for (2) is greatest. This is rephrased in RS as choosing the strategy (e, d) which maximizes (2).

Now consider the LK system, as described by Krantz, et al. (1971). It is more formal as regards probabilities than is the RS framework in that an algebra of subsets (A) of a set X is explicitly introduced. These subsets "represent chance events to which probabilities ultimately will be assigned," (p. 372). A set C of consequences (c) is also introduced. Then, for non-null events A (those which will be given non-zero probabilities), a decision conditional on A is defined as a function

$$f_A: A \rightarrow C$$

which assigns a consequence to each element of the event A. For events A and B with no elements in common and conditional decisions f_A and g_B the decision $f_A \cup g_B$ is defined for each element in $A \cup B$. Specifically, this function assigns a consequence using f_A if the element is in A and using g_B if the element is in B.

Axioms are introduced which allow the development of a probability measure on the algebra of events and a utility function which assigns a real valued utility to each decision in D , the set of all conditional decisions under consideration. These utilities preserve the preference ordering which is assumed to exist on D . Moreover, they are compatible with the probability measure in the sense that

$$u(f_A \cup g_B) = u(f_A)P(A|A \cup B) + u(g_B)P(B|A \cup B) ,$$

thus assigning a conditional expected utility to the composite decision based on the utilities of the component decisions. Clearly, more general expectations than the preceding will be assumed to be appropriate even though, strictly speaking, the LK development does not justify their use.

For the translation, begin by identifying X with $\Theta \times Z$. In each system it is the relevant subsets of these sets to which probabilities are assigned. Next, let C be identified with Re . Since the RS system includes no separately identified consequences, it seems easiest to think of these directly as utilities. The most elementary level of decision in the RS system may be represented in LK terms by defining

$$f_{a,z}: \Theta \times \{z\} \rightarrow Re$$

as

$$f_{a,z}(\theta, z) = u(e, z, a, \theta)$$

for fixed $z \in Z_e$. Here the decision to choose act a , given result z of experiment e , produces a consequence $u(e, z, a, \theta)$ for each state $\theta \in \Theta$. The decision $f_{a,z}$ may actually be thought of as a union of even more

elementary decisions, each of which assigns a utility to a single point (θ, z) . In this spirit, the utility of $f_{a,z}$ may be expressed as an expectation:

$$u(f_{a,z}) = E[u(e, z, a, \theta) | \theta \times \{z\}] \quad (3)$$

Thus a representation of (1) has been provided in the LK system. Note that the expectation in (3) is being taken, in effect, over the posterior distribution of θ given z .

To deal with the next level of decision for RS, namely a choice among decision rules, define the conditional decision

$$g_{d,e} = \bigcup_{z \in Z_e} f_{d(z),z}$$

on the set $e = \theta \times Z_e$. Once again, the utility of the composite decision can be represented as the conditional expected utility of its components:

$$u(g_{d,e}) = E[u(f_{d(z),z}) | e] \quad .$$

Here expectation is with respect to the prior predictive distribution of z .

Using (3), this can be rewritten as

$$u(g_{d,e}) = E[u(e, z, a, \theta) | e] \quad , \quad (4)$$

which is the counterpart of (2) in the RS system.

Finally, the choice of a strategy (e, d) may be simply described as selection of the conditional decision (g, d, e) whose utility is maximal across all $e \in E$. With this basis, both extensive and normal form analyses are simply explicated in the LK system, always using the principle that the utilities of decisions reflect preference orderings. To be more ex-

plicit, normal form analysis directly considers a choice among the decisions $g_{d,e}$. Extensive form, on the other hand, begins with a choice among $f_{a,z}$ for each $z \in Z_e$.

An immediate conceptual advantage of this treatment over that given in RS is that all levels of analysis take place on the same basic entities, namely conditional decisions.

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